INVESTIGATIONS ON ATMOSPHERICS IN HIGH-FREQUENCY CHANNELS*

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ABSTRACT. The results of investigations on atmospherics carried out at Dacca during the monsoon time of 1940 on a range of frequencies from 2 Mc. to 20 Mc. are given in this paper. The peak method of measurements was employed and experiments were carried out along the following lines:

I. Determinations of the numbers of atmospherics from different directions in different frequency channels at different times of the day, with special reference to the sunrise and the sunset periods.

II. Measurements of the field-strengths of the atmospherics from the east-west direction (and occasionally from the north-south) in different frequency channels at different times of the day with special reference to the sunrise and the sunset periods.

Usually one and occasionally two maxima, some minutes *before* the ground sunrise were observed in both sets of experiments. Soon after the maximum, the field-strength and also the number decreased very rapidly and continued diminishing till some time after the sunrise. There was a subsequent rise indicating a maximum an hour or two after the ground sunrise. The field-strength as well as number were found to be minimum from about 12 to 2 in the day. One maximum both in number and field-strength was observed some minutes *after* the ground sunset. In some observations, a maximum appeared about the time of ground sunset.

A general explanation has been given of the observed maximum *before* the ground sunrise and *after* the ground sunset in terms of the changes in the ionospheric conditions during the transition period. The two maxima observed could be associated with the E- and the F-layers. According to this view, it has been possible to locate the source of the distant atmospherics from the observed position of the maximum in relation to the ground sunset or sunrise. The basic idea in this explanation has been verified by observing the position of the field-strength maximum for short-wave signals from the Calcutta station during and after the sunset time.

III. The frequency distribution of the atmospherics from the east-west direction was studied in two different ranges of frequencies, *viz.*, 2 Mc.—5 Mc. (60 m—150 m) and 10 Mc.—20Mc. (15 m—30 m) under the following heads:

(*a*) Measurements of field-strengths of *distant* atmospherics during *day* and *night*.

(*b*) Measurements of field-strengths of the atmospherics of *near* origin during local thunderstorms.

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(c) Measurements of field-strengths of the "rain-statics," when there was continuous drizzle with slight flashes but with no thunder.

All the experimental results on the frequency distribution of the atmospherics in the different cases have been satisfactorily explained.

IV. The average values of the daily maximum peak-strength of the atmospherics on 5 Mc. and 10 Mc. during the usual morning, afternoon and night programme hours for the monsoon months were determined and an estimate of the signal-strength values for good reception about this time at Dacca on these frequencies has been made from these averages.

INTRODUCTION

The study of atmospherics in India is of extreme importance in order to determine the best conditions for radio communication. Every radio-listner knows that except for a few months in the year there are all sorts of atmospheric disturbances. In fact during the monsoon time in India the field-strengths of the atmospherics could be as high as 100 times or even more than the corresponding values in the temperate countries. Systematic investigations on the subject under tropical conditions had, therefore, been felt necessary for the past few years when several broadcasting stations were opened in India by the All-India Radio. It was increasingly evident that a better understanding of the atmospheric noise over a wide range of broadcast frequencies was desirable. Recently some measurements were carried out at the Kanodia Electrical Communication Engineering Laboratories, University of Calcutta, on wave-lengths from 50 metres to 500 metres (*i.e.*, from 0.6 to 6 megacycles), by S. P. Chakravarti, P. B. Ghosh, and H. Ghosh.[1] Some work on very long wave-lengths had also been previously reported by Chakravarty and Paranjpye[2] on the atmospherics at Bangalore during the polar year 1932-33. Some investigations were also made in this laboratory by Khastgir and Rao[3] on medium wave-bands from 150 metres to 1200 metres (*i.e.*, from 250 Kc. to 2000 Kc.) on the atmospherics at Dacca following the 'warbler' method of noise measurements. The frequency distribution of the atmospherics was studied and the diurnal characteristics of the atmospherics were investigated with special reference to the sun-rise and sunset times. Similar studies were also made by Khastgir and Ray[4] following the peak-method of measurements over a range of medium wave-lengths 150 metres to 800 metres (*i.e.*, from 375 Kc. to 2000 Kc.). In the present investigation these measurements were extended to still shorter wave-lengths. Experiments were carried out on wave-lengths from 15 metres to 150 metres (*i.e.*, from 2 Mc. to 20 Mc.) which cover practically all the broadcasting short and shorter medium wave-bands. All measurements were made during the monsoon months of 1940.

It should be mentioned here that similar noise measurements were carried out by Espenschied, Anderson and Bailey[5] on long wave-lengths from 5,300 metres to 20,000 metres (*i.e.*, from 15 Kc. to 55 Kc.) following the warbler method in several receiving centres in England. They studied the diurnal and seasonal characteristics of the noise and also the frequency distribution of the atmospherics within their range of frequencies during the day and the night. An elaborate investigation on similar lines was later made by Potter [6] in the range of short wave-lengths from 15 m. to 60 m. (*i.e.*, from 5 Mc. to 20 Mc.). Mention should also be made of the recent work done on similar lines by Schafer and Goodall[7] on a wave-length of 2 metres (150 Mc.).

METHOD OF M ASUREMENT AND EQUIPMENT

In measuring the intensity of the received atmospherics, the peak-method of measurement, as followed by Potter,[6] was employed in the investigation. In obtaining the field-strength values, only the peak crashes were considered during the period of observations. The measurements were made on a specially constructed 3-valve receiver with a balanced galvanometer in the anode circuit of the last valve of the receiver. The major deflections were noted over a period of 2 or 3 minutes. *The deflections greater than a third of the maximum deflection were only considered and the arithmetic mean of these larger deflections was taken as the equivalent signal deflection in the calculation of the field-strength of the atmospherics.* This arithmetical mean was expressed as micro-volts per metre.

The diagram of the receiving set is shown in Fig. 1. The anode current of the detector valve was balanced as shown in the diagram.

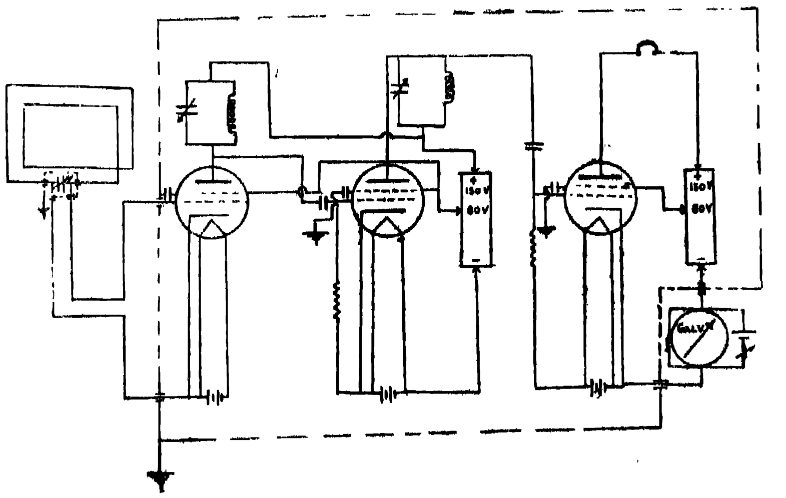


FIG. 1

The receiving set with batteries was placed inside a shielded cabinet. A frame aerial having a few turns of thick copper wire was employed with a tuning condenser in parallel. In counting the number of atmospherics on higher frequencies, a L.F. amplifier of conventional design was sometimes used.

EXPERIMENTAL RESULTS

A. *Total number of atmospherics per minute for different directions at different hours of the day on some specified frequencies*

The numbers of atmospherics within a short interval of time were counted usually in two specified directions, north-south and east-west, on different frequencies, *viz.*, 3 Mc., 5 Mc., 10 Mc. and 20 Mc. (*i.e.*, 100 m., 60 m., 30 m. and 15 m). In the case of 3 Mc., observations were also taken in the direction 45° between N. and E.

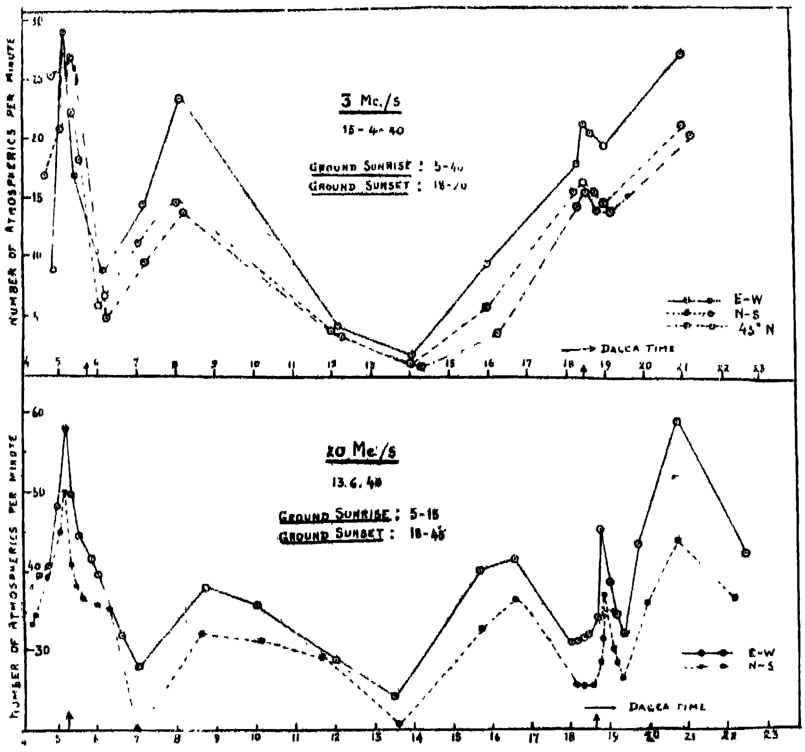


FIG. 2(*a*)

Some typical curves are shown in Fig. 2. These curves reveal certain general features in the diurnal characteristics of the atmospherics. The general features in these atmospherics counts can be summarised as follows :

(1) The number of atmospherics per min. from any direction usually showed *a maximum* some minutes *before the ground sunrise.* The number then decreased sharply about the ground sunrise time. In some observations *two distinct maxima*, one after another, *both before the ground sunrise* were observed.

(2) The minimum number of atmospherics occurred between 12 and 2 during the day.

(3) The number of atmospherics increased in the afternoon.

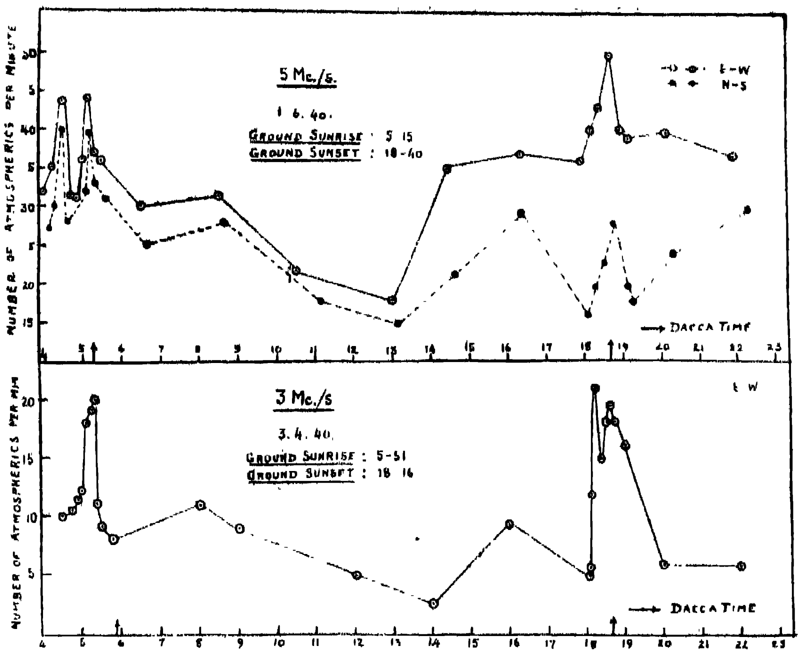


FIG. 2(*b*)

(4) Usually there was a *maximum*, some minutes *after the ground sunset.* In some observations there was a maximum about the ground sunset time.

In Fig. 3 are shown a few more sunrise curves. During the sunrise and the sunset times, observations were usually taken at intervals of 5 min. and averaged over 2 minutes.

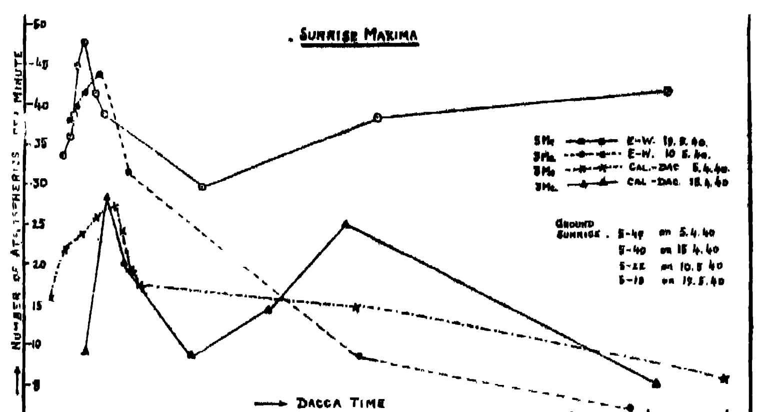


FIG. 3

B. *Peak Field-strengths of the atmospherics at different hours of the day on some specified frequencies*

The diurnal variations of the peak field-strength of atmospherics from the E-W direction (and occasionally from the north-south) were studied from about

4 A.M. to about 11 P.M. on three different frequencies : 5 Mc., 10 Mc. and 20 Mc. (*i.e.*, 60 m., 30 m. and 15 m.). The following types of results were usually obtained :

(*i*) *One maximum* some minutes *before* the ground sunrise time and *another maximum* some minutes *after* the ground sunset were observed.

(*ii*) *Two maxima* which were close together were sometimes observed *before* the ground sunrise and *only one maximum definitely after* the ground sunset was observed.

(*iii*) Occasionally *a maximum* was observed at the ground sunset time.

It should be noted that the field-strength variations were found almost similar to the variations of the numbers of atmospherics from hour to hour.

Some typical experimental results on 5 Mc. are shown in Fig. 4.

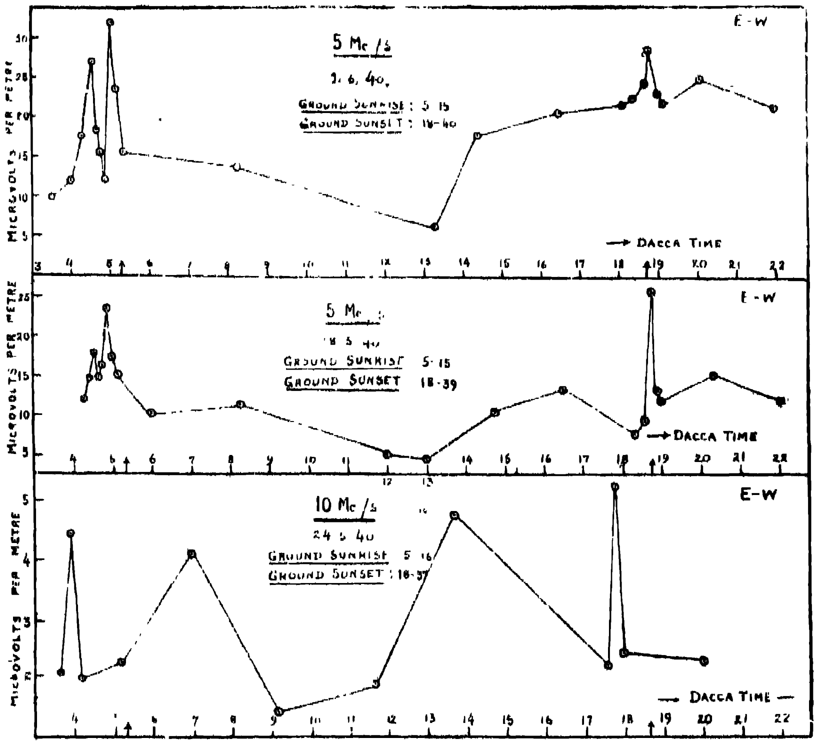


FIG. 4

THEORY OF THE SUNRISE AND THE SUNSET MAXIMA

Years ago the sunrise and the sunset effects had been observed by Eccles and others.[8] These effects had been later observed by Espenschied, Anderson and Bailey[5] and also by Potter.[6]

Potter attempted a general explanation of the effects observed and also of the double peak which was at times observed by him, but in view of the present knowledge of the ionosphere, such an explanation does not seem to be at all feasible. For very long waves Namba[9] suggested an explanation of the sunset and sunrise phenomena. According to his view, the reflection at the ionized layer is *metallic* before sunset and *dielectric* after sunset and the sunrise and the sunset effects are due to this transition in the reflection characteristics of the layer.

We offer here an explanation of the phenomena in the light of our experimental results in the following manner :—

(a) *A General Explanation of the Sunrise and the Sunset Effects*

A lightning stroke gives rise to damped electromagnetic pulses and each such pulse can be regarded as consisting of all the frequencies in the Fourier series. When lightning takes place at some distance from the receiving point, the electromagnetic pulse may arrive at the receiver after reflection from the ionospheric layer.

It is now well-known that the E-layer ionization gradually falls during the night and attains a minimum value in the small hours of the morning. The ionization then begins to increase and the increase is rather rapid during the sunrise period. During the sunset period too, the ionization is found to fall rather abruptly. The minimum ionization in early morning can be associated with the maximum observed before sunrise in the field-strength of the atmospherics. Before the ionization minimum is attained, it is evident that there will be a gradual decrease in attenuation due to gradually decreasing electron collision frequency in the layer causing thereby a gradual increase in intensity of the downcoming waves till there is a peak when the E-layer ionization is minimum. After the minimum, as the collision frequency considerably increases the attenuation rapidly increases. This causes a rapid fall in the intensity of the downcoming wave. The gradual formation of an absorbing layer, the D-layer, after sunrise would also increase the attenuation. This explains ina general way the sunrise maximum both in numbers and field-strengths of the atmospherics received in a particular frequency channel. It is however evident that when the observed field-strength is greater, the greater would be the numbers of atmospherics recorded ; because with greater or less intensities, larger or smaller numbers of the atmospherics could be distinguished.

The explanation of the sunset maximum is also somewhat similar. Before the sunset period it is known that there is a gradual decrease in the E-layer ionization. It is therefore expected that there would be a gradual rise in the intensity of downcoming waves due to a continuous fall in ionospheric absorption or attenuation. At the sunset time, when the ionizing solar rays are suddenly withdrawn, there is a sudden and a perceptible decrease in electron-concentration, so that the downcoming waves, originally coming from the distant source of atmospherics would be much less deviated and would fail to reach the receiving point. Thus at this point of the withdrawal of the solar rays, the intensity would fall, although attenuation would be less. Subsequently, however, the gradually decreasing attenuation would assert itself and the intensity would increase. The subsequent increase in intensity would also be partly due to the gradual disappearance of the D-layer after sunset.

The double peaks which were usually observed before the ground sunrise can be explained in terms of the two layers E and F. It is, however, known that the F-layer ionization also indicates a rapid increase in value about the sunrise (in the layer) and also a sharp fall about the sunset time (in the layer).

(b) *The Positions of the Sunrise and Sunset Maxima*

The work on the early morning increase of the E-layer ionization by Mitra[10] and his associates has shown that the ionization begins to increase *not* when the early morning solar rays strike the E-layer by grazing the surface of the earth *but* when the rays strike the layer by grazing the top of the ozonosphere at a height of 35 Km. from the earth's surface. The sun's rays in order to produce ionization in the E-layer should evidently pass over the ozone region so as not to have its shorter wave-lengths absorbed by ozone. Let the source of the atmospheric disturbance and the receiving point be represented in the *East-West plane* by S and R respectively on the earth's surface. Then the pulse of the atmospherics which contains all the frequencies of the Fourier series would reach the receiving point after reflection at A in the ionospheric layer. It will be evident from the diagram (Fig. 5) that the ionization in this region A would begin to increase only when the sun's rays would pass over the tangent from A to the

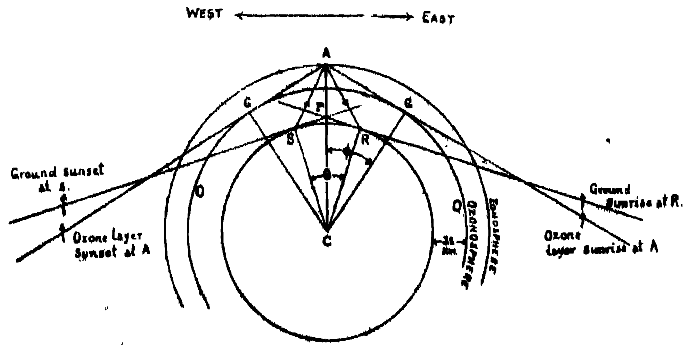


FIG. 5

top of the ozone layer OO. The ground sunrise or sunset at the receiving point is of course easily determined by drawing a tangent plane to the earth at the receiving site. We shall consider first the case of sunrise. Let us draw a tangent from A touching the ozone layer at G and let the tangent to the earth at the receiving point cut the straight lines joining the centre C of the earth and the point A where the ionospheric reflection takes place at the point P. If the angular distance between the noise source and the receiving point be denoted by θ, then the angle PCR would be $\theta/2$. Denoting the angle ACG by ϕ, it can be easily seen that the instant when the sun's rays would begin to produce ionization in the region A by grazing the top of the ozone layer would be earlier or later than the ground-sunrise at R, according as $\phi >$ or $< \theta/2$. Thus if the receiving point R is to the east of the noise source the difference between the instant of ground sunrise at the receiving point and the instant when the ionization begins to increase in the region A would be given by :—

$$\Delta T = 4(\phi - \theta/2) = (4\phi - 2\theta) \text{ minutes.}$$

On the other hand, if the receiving point R is to the west of the noise source S, the ionization at the reflection point in the ionosphere would begin to increase invariably before the ground sunrise at the receiving point. (This can be easily understood if we suppose that the locations of S and R are interchanged, and that the reflection point A remains in the same position.) In this case the time-difference would be given by $(4\phi + 2\theta)$ minutes.

From these considerations and in view of the nature of variation of the E-layer ionization during the small hours of the morning, it can thus be said that a maximum would be observed $(4\phi + 2\theta)$ min. before the ground sunrise, if the receiving point is to the west of the noise source, and if the receiving point is to the east of the noise source, the maximum would be expected at $(4\phi - 2\theta)$ min. before, provided $\phi > \theta/2$. Similar arguments would apply to the case of the sunset. It should be noted that the sunset maximum would appear *after* the ground sunset, provided $\phi > \theta/2$; whereas under the same condition, the sunrise maximum would appear *before* the ground sunrise.

With short waves when there is reflection from the F-layer also, another maximum is also expected $(4\phi' \mp 2\theta)$ min. before the ground sunrise, where ϕ' for the F-layer corresponds to the angle ϕ in the case of the E-layer. We are assuming here that the F-layer ionization begins to increase when the sun's rays grazing the ozonosphere reach the region in the F-layer where the reflection is taking place. Measurements of the F-layer ionization do not, however, give definite information on the point.[11] Sometimes the increase in ionization takes place some minutes *after* the sunrise time in the F-layer and sometimes *before*. It is significant, however, that the ionization does not begin to fall till about 1½ hours after the sunset in the F-layer.[12] This perhaps accounts for the absence of the sunset maximum which could be associated with F-layer.

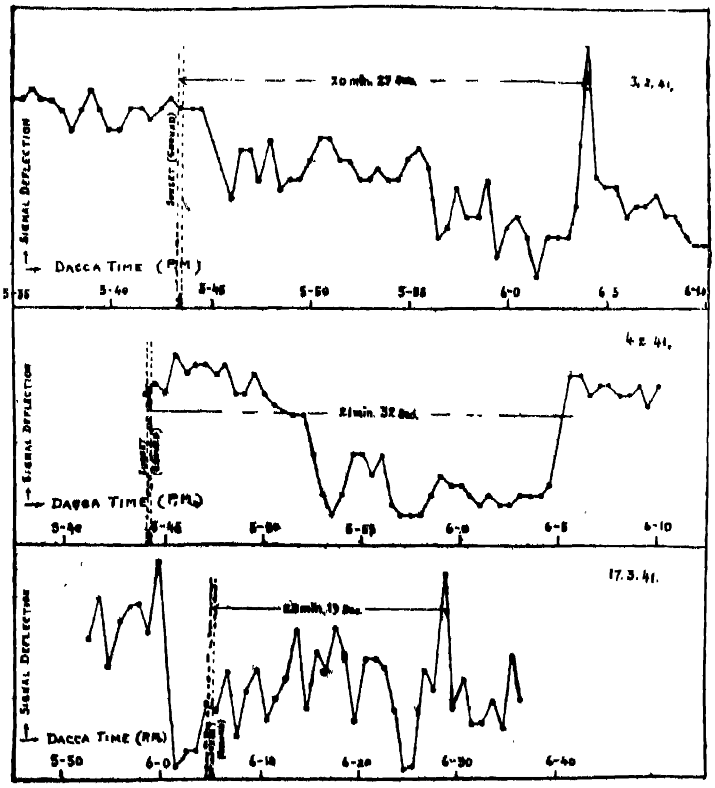
Occasionally however, a maximum was observed about the ground sunset time. It is possible that a sudden fall in temperature and electrical conductivity of the atmosphere, a rise in humidity and a change in the other meteorological conditions during the sunset period can account for a maximum intensity of a distant thunderstorm field.[13]

EXPERIMENTAL TEST OF THE THEORY OF THE SUNRISE AND THE SUNSET MAXIMA

According to the suggested theory of the sunrise and the sunset maxima in the variation of the field-strengths of the atmospherics, we would expect similar effects in the signal-strength observations of a distant transmitter at times of ground sunrise and sunset. In Fig. 6 typical curves showing signal-strength variations of the Calcutta short-wave station (4840 Kc., $\lambda=61.98$ m.) are given for three different days. A distinct maximum is evident in all the three cases. In table 1 are given the times of occurrence of the maximum after the ground sunset for the three days :

TABLE I

No.	Dates of observation	Times of occurrence of signal maximum after ground sunset	Ground sunset time
1	3.2.41	20 min. 27 sec.	17h. 43′33″
2	4.2.41	21 min. 32 sec.	17h. 44′13″
3	17.3.41	23 min. 19 sec.	18h. 5′11″



CALCUTTA SIGNAL (4840 Kc./s)
OBSERVED AT DACCA.

FIG. 6

The time of occurrence of the sunset maximum can also be computed from the following data :—

Radius of the earth $=6371$ Km.

Reflection height in the E-layer before sunset $=80$ Km.

Top of the ozone layer $=35$ Km. With these values $\phi=6^\circ.9$

Since the difference between Calcutta and Dacca local times $=8$ minutes,

$$\therefore \qquad \theta=2^\circ.$$

The signal maximum is therefore expected at $(4\phi-2\theta)$ min., *i.e.*, 23 min. 36 sec. after ground sunset. The time calculated on the basis of our explanation is thus in good agreement with the observed time of occurrence of the sunset maximum.

EXAMINATION OF THE EXPERIMENTAL RESULTS ON THE SUNRISE AND THE SUNSET MAXIMA

According to the theory of the sunrise and sunset maxima, the position of the maximum in respect of time would give an indication of the location of the source of atmospherics. If the time of occurrence of the maximum is less than 4ϕ min. before ground sunrise or after ground sunset, it is evident that the disturbance is coming from the west and if the time of occurrence is more than 4ϕ min. before ground sunrise or after ground sunset, the disturbance may either come from the east or from the west. It is possible to draw a curve showing the position of the maximum with reference to the ground sunrise or the sunset and the approximate location of the atmospheric disturbance in miles. Taking the E-layer reflection height to be 80 Km. and the top of the ozone layer 35 Km., the distance of the source of the received atmospherics was found to lie between 50 miles and 750 miles, either in the east or in the west of the receiving point.

If the double sunrise peak is to be associated with the E-layer and the F-layer reflections respectively, it is possible also to calculate approximately the separation in time between the two intensity maxima. The observed values of this time

TABLE II

Frequency channel	Observed time difference between two peaks (in minutes)	Theoretical values of ΔT (in minutes) H⟶Reflection height in F-layer
5 Mc.	21.0	24.0 (H = 200 Km.)
5 Mc.	29.0	31 (H = 250 Km.)
20 Mc.	15.0	16 (H = 150 Km.) 24 (H = 200 Km.)
800 Kc.	19.0	16 (H = 150 Km.)
800 Kc.	15.0	16 (H = 150 Km.)

difference for some typical cases are given in table II. The theoretical values which would give approximate agreement for suitable values of the reflection height are also shown in the table. The results of similar experiments with R. G. Basak on 800 Kc. (*vide* Current Science, Oct. 1942) are also incorporated in this table.

Considering the uncertainty in the actual reflection height the agreement can be regarded as satisfactory.

FREQUENCY DISTRIBUTION OF THE ATMOSPHERICS

The measurements of the atmospheric field-strengths as a function of frequency were undertaken for two frequency ranges, *viz.* (1) from 2 to 5 megacycles (60 m.—150 m.) and (2) from 10 to 20 megacycles (15 m.—60 m.). The following experiments on the frequency distribution of the field-strengths of the atmospherics were performed *both during the day time and the night*:

EXPERIMENTAL RESULTS

(*i*) *Experiments on distant Atmospherics during the Day*

Some typical experimental results for the frequency ranges 2 Mc.—5 Mc. and 10 Mc.—20 Mc. are shown in Fig. 7.

It is to be observed that during the day, the field-strength of the distant atmospherics when plotted against $\frac{1}{f^2}$ gave an approximate straight line only

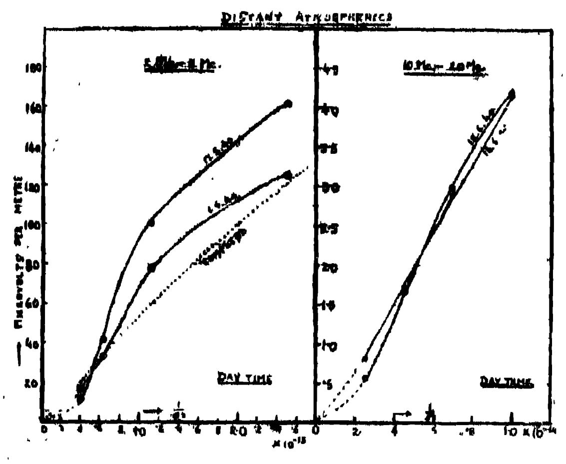


FIG. 7

in one case. In the other cases, the E—$\frac{1}{f^2}$ curve was found to be straight over a limited range only.

(ii) Experiments on distant atmospherics during the night when the sky-waves were predominant

Some typical results are illustrated in Fig. 8.

In both the frequency ranges, it was found that during the night the field-strength of the distant atmospherics decreased exponentially with the increase of frequency.

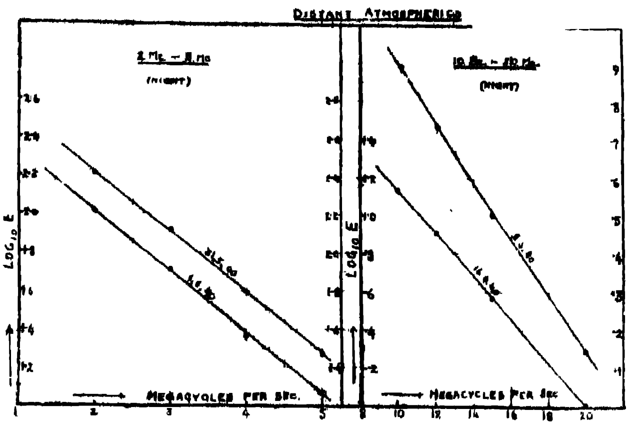


FIG. 8

(iii) Atmospherics due to local thunderstorms

The experimental results are illustrated in Fig. 9. It can be seen that the field-strength, when plotted against the reciprocal of frequency gave a straight line in each set of observations. The relation between field-strength and frequency was of the form : $E = A + \frac{B}{f}$, where A and B are constants.

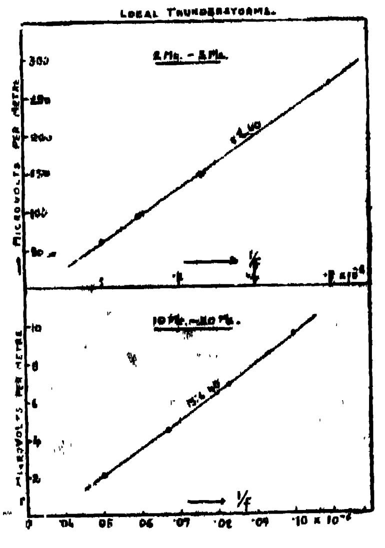


FIG. 9

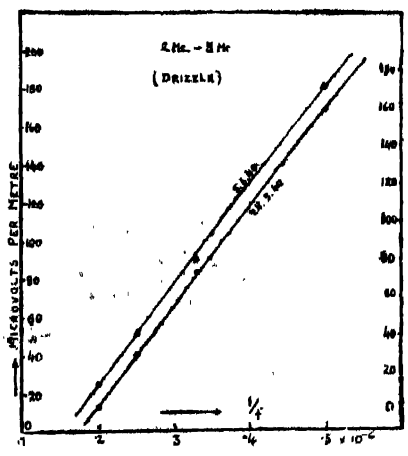


FIG. 10

(iv) *Observations on "Rain statics"*

On certain days when there was continuous drizzle for hours together with slight flashes but with no thunder, some experiments were performed to study the frequency distribution of the received atmospherics. Two sets of experimental results are illustrated in Fig. 10. It should be noticed that in these experiments also, as in the case of experiments during local thunderstorms, the relation between the measured field-strength and the frequency was of the same form, *viz.*, $E = A + \frac{B}{f}$, where A and B are constants.

THEORETICAL CONSIDERATIONS IN THE STUDY OF THE FREQUENCY DISTRIBUTION OF ATMOSPHERICS

I. *Distant Atmospherics*

Let us suppose that the source of atmospherics gives rise to damped sinuous waves. It can be seen from Burch and Bloesma's'[4] Fourier analysis of such waves that for frequencies much higher than the frequency of the received atmospherics, the amplitude of the particular term involving the frequency to which the receiver is tuned is inversely proportional to the square of that frequency. Hence the Fourier co-efficient of the particular component involving the high frequency f is given by

$$B_f = \frac{A}{f^2} \qquad \ldots \quad (1)$$

where A is some constant.

Now neglecting any kind of attenuation, we know that the field-strength at distance r from a dipole aerial radiating sinuous waves is obtained from

$$E = f.\left[\frac{37.28 \times 2\pi(hI)}{rc}\right],$$

where hI is the metre-amperage of the transmitter and c the velocity of light. Thus at a particular distance r we have $E = K.f$, where K is constant.

Considering now the particular Fourier component of frequency f, we can write

$$E = \frac{A}{f^2}.K.f \quad \text{or} \quad \frac{A.K}{f}.$$

We shall here take the following cases:

(a) *When the ground waves alone are present.*—In this case the field-strength of the atmospherics received in frequency channel f is given by

$$E = \frac{A.K}{f}.A_1$$

where A_1 is the ground-attenuation factor.

According to Norton[15] the ground-wave attenuation factor is given by

$$A_1=\left|1+i\sqrt{\pi p_1}\,e^{-p_1}.\quad erfc(-i\sqrt{p_1})\right| \quad \ldots \quad (3)$$

where $$p_1=pe^{ib} \quad \ldots \quad (4)$$

$$p=\frac{\pi}{x}\cdot\frac{r}{\lambda}\cdot\cos b$$

$$=\frac{\pi}{\epsilon+1}\,\frac{r}{\lambda}\sin b \quad \ldots \quad (5)$$

$$\tan b=\frac{\epsilon+1}{x}=\left\{\frac{\epsilon+1}{2\sigma}\right\}f \quad \ldots \quad (6)$$

$$x=\frac{2\sigma}{f}\ (\sigma \text{ in e.s.u.}) \quad \ldots \quad (7)$$

$r=$ actual distance from the source
$p=$ numerical distance
and $\lambda=$ wave-length.

It can be shown that for $p > 20$

$$A_1=\frac{1}{2p} \quad \ldots \quad (8)$$

Now, putting $\frac{\epsilon+1}{2\sigma}=a$, we have $\tan b=a.f.$

On putting again $\frac{c(\epsilon+1)}{2\pi r}=B$, we can show

$$A_1=\frac{B}{f}\left\{1+\frac{1}{a^2f^2}\right\}^{\frac{1}{2}} \quad \ldots \quad (9)$$

so that $$E=\frac{A.K}{f}.\ A_1=\frac{A.K.B}{f^2}\left(1+\frac{1}{a^2f^2}\right)^{\frac{1}{2}}. \quad \ldots \quad (10)$$

For the shorter waves, we can neglect $1/af$,

so that $$E\approx\frac{A.K.B}{f^2}\propto\frac{1}{f^2}. \quad \ldots \quad (11)$$

Moullin[16] also obtained a somewhat similar expression.

(*b*) *When the Sky Waves alone are present.*—In the case of the sky waves which are returned from the ionosphere, the constant K in (1) should be multiplied by $\sin i_0$, since the sky path would be $r/\sin i_0$, where i_0=angle of incidence at the ionized layer. Thus without considering attenuation, we have in this case

$$E=\frac{A.K}{f}\sin i_0 \quad (12)$$

This should be multiplied by the relevent attenuation factor to get the actual field-strength of the sky waves.

Long Waves

For low-frequency waves (100 Kc. or below), the ionosphere behaves as a good reflecting surface. According to Namba's[9] calculations, for values of the angle of incidence corresponding to fairly long distances the reflected intensity is usually larger at night than during the day. During the night, however, the reflection is practically independent of wave-length. Hence for the night-time observations

$$E = \frac{A.K. \sin i_0}{f} A_2$$

where A_2 = attenuation constant which is independent of frequency.

Thus $$E = \frac{\text{constant}}{f}. \qquad \dots (13)$$

Dellinger's[17] report on radio propagation data mentions this simple inverse relationship in the case of night atmospherics.

Medium Waves

When the frequency of the wave is below the critical penetration frequency, the wave is sufficiently refracted in the E-layer and gets returned to the surface of the earth. During the day, there is no appreciable amount of downcoming wave. During the night, the sky wave intensity may be considerable.

Assuming an exponential gradient for electron concentration in the ionized layer, (*viz.*, electron density $N = pe^{qz_0}$, where z_0 is the reflection height above the boundary of the layer and p and q are constants), it has been shown by Namba[9] that the total attenuation along the curved path, when the wave gets bent and returns to the earth will be given by

$$A_2 = \frac{2\nu}{cq} \left[\cos^2 i_0 + \frac{2z}{r_0} \right] \qquad \dots (14)$$

where ν = electron-collision frequency, r_0 the radius of the earth and c the velocity of light. Here the collision frequency could be taken proportional to frequency,[18] *i.e.*, $\nu = k.f$, where k is constant. Since the height z of the ionized layer above the ground is much smaller than the radius of the earth, we can approximately write :

$$A_2 = a.f, \qquad \dots (15)$$

where $$a = \frac{2k}{cq} \cos^2 i_0 = \text{constant},$$

when the source of the atmospherics and the receiving point are fixed.

Hence the field-strength of the particular Fourier component of frequency f as returned from the E-layer will be

$$E=\frac{A.K.\sin i_0}{f}.\ A_2=\frac{A.K.\sin i_0}{f}.e^{-af}$$

or

$$E=\frac{\text{const.}}{f}.e^{-af} \qquad \dots (16)$$

i.e.,

$$\log E+\log f=\text{constant}-af.$$

The frequency here is of a high order, so that the variation of $\log f$ with f is rather small in the limited range of frequencies. Thus we can write

$$\text{Log } E=\text{const.}-af. \qquad \dots (17)$$

In most cases, our experimental results *during the night* in the medium and high frequency ranges were found in accordance with this exponential law of decrease of field-strength with frequency.

Short Waves

High-frequency waves which are of frequencies higher than the critical penetration frequency penetrate through the E-layer and reach the F-layer. They are subsequently returned from the higher layer, when the maximum electron density of that layer is sufficient for the bending of such waves. With these waves, we have to consider attenuation during transmission through the E-layer and attenuation along the curved path in the F-layer while getting bent and returning to the earth's surface. The first attenuation can be taken as inversely proportional to the frequency and the second one can be taken as varying with frequency in accordance with (14) or (15). Thus the field-strength of such downcoming waves can be written as

$$E=\frac{M}{f}.\ \frac{e^{-m}}{f^2}.\ e^{-af} \qquad \dots (18),$$

where M and m are constants. Usually at night $m/f^2 << 1$,

so that $$E=\frac{M}{f}\left(1-\frac{m}{f^2}\right)e^{-af} \simeq \frac{M}{f}e^{-af},$$ which is similar to (16).

(c) When Ground Waves and Sky Waves are both present.—Let n_g and n_s be the fractions representing the two portions reaching the receiver by the ground path and sky path, so that $n_g+n_s=1$. The field-strength at the receiving point will then be given by

$$E=\sqrt{\left(\frac{A.K.B.}{f^2}\right)^2 n_g^2+\left(\frac{A.K.\sin i_0}{f}\right)^2 n_s^2 e^{-2af}}$$

$$=\frac{D}{f^2}\left[1+b.f.^2e^{-2af}\right]^{\frac{1}{2}} \qquad \ldots \quad (19)$$

where $\quad D=n_g.\ A.K.B$ and $b=\frac{n_s^2}{n_g^2}\cdot\frac{\sin^2 i_0}{B^2}$. $\left[\text{Here}\quad B=\frac{c(\epsilon+1)}{2\pi r}.\right]$

Putting $\quad \Delta=D(1+bf^2e^{-2af})^{\frac{1}{2}}$,

we get $\quad E=\frac{\Delta}{f^2}$.

The slope of the curve showing E against $1/f^2$ would be given by Δ. It is evident from (19) that for values of $af>1$, the slope would increase with the increase of $1/f^2$ and after attaining a maximum value when $af=1$, the slope would decrease for $af<1$ with the increasing value of $1/f^2$; the curvature would change sign when $af=1$.

Our day observations in the two frequency ranges 2 Mc.—5 Mc. and 10 Mc.—20 Mc. showed that the field-strength E, when plotted against $1/f^2$, gave a straight line *only in very few cases*. In these few cases, we may suppose that the ground waves were predominant, so that $\frac{n_s}{n_g}=0$ and we get $E=\frac{D}{f^2}$. In most cases, however, the sky waves were not negligible and the curve $E-\frac{1}{f^2}$ was straight only over a limited range. The experimental curves could be explained according to (19).

We have drawn an approximate theoretical curve for the range 2 Mc—5 Mc. taking

r = distance between the source of atmospherics and the receiving point = 250 Km.

$i_0=40°$

ϵ = Effective dielectric constant of the earth = 10 e.s.u.

and $\quad n_s=n_g$.

The theoretical curve is shown in Fig. 7, where the experimental curves are also shown.

II. *Atmospherics due to local Thunderstorms*

In the case of local thunderstorms, the source of the atmospherics is near the receiving point. The ground attenuation or the ionospheric attenuation is not to be considered in this case. If we suppose now that the lightning discharge gives rise to damped sinuous waves, the field-strength of the received atmospherics on a high frequency f would be given by (1), *viz.*,

$$E=\frac{A.K.}{f}=\frac{\text{const.}}{f}$$

It is, however, known that the electrical discharges in thunderstorms would often consist of disturbances in the nature of sharp impulses. Let us represent this impulse by $f(t)=-f(-t)$, which tends to zero sufficiently rapidly for large values of the time t. Let us also suppose that near $t=0$ the function tends to have very large values. The Fourier coefficient of angular frequency ω for such a function is then given by

$$
\begin{aligned}
B_f = \int_{-\infty}^{\infty} f(t).\, e^{i\omega t}\, dt &= \int_{0}^{\infty} f(t).\, e^{i\omega t}\, dt + \int_{\infty}^{0} f(t).\, e^{i\omega t}\, dt \\
&= \int_{0}^{\infty} f(t).\, e^{i\omega t}\, dt + \int_{0}^{\infty} f(-t).\, e^{-i\omega t}\, dt \\
&= 2i \int_{0}^{\infty} f(t) \sin \omega t.\, dt.
\end{aligned}
$$

Now if $f(t) \int \frac{1}{e^{2\pi\lambda t}-1}$ where λ determines the rapidity with which the function tends to zero with the increase of time t, then the Fourier coefficient of angular frequency ω will be $\int_0^\infty \frac{\sin \omega t}{e^{2\pi\lambda t}-1}\, dt$. Putting $\tau=\lambda t$, we have[19]

$$
B_f = \frac{1}{\lambda}\int_0^\infty \frac{\sin \omega/\lambda d\tau}{e^{2\pi\tau}-1} = \frac{1}{\lambda}\left[\frac{1}{4}\,\frac{e^{\omega/\lambda}+1}{e^{\omega/\lambda}-1} - \frac{\lambda}{2\omega}\right]. \qquad \dots (20)
$$

For large values of ω, this is reduced to $\left(\frac{1}{4\lambda}-\frac{1}{\omega}\right)$, so that for large values of λ when the function comes down sufficiently to zero, the Fourier coefficient will be varying as $\frac{1}{\omega}$, *i.e.*, $B_f = \frac{\text{const.}}{f}$. To obtain the field-strength at the receiving point, we have to multiply this by f, so that $E = \frac{\text{const.}}{f} f = \text{const.}$

If we suppose that the lightning discharges give rise to damped sinuous waves and also impulses of short duration, it is easily seen that the field-strength of the atmospherics in local thunderstorm centres will be of the form: $E = A + \frac{B}{f}$, where A and B are constants. Our experimental results are in agreement with this relation.

III. "*Rain-statics*"

The observed field-strength of the atmospherics received during continuous drizzle in the day varied with the frequency in the same way as the field-strength of the atmospherics from local thunderstorm centres. It can therefore be conjectured that the source of the disturbance was near the receiving point and that its nature was similar to that of the lightning discharges. It is known, however, that when many thousands of charged particles of water vapour coalesce to form a rain drop, there is a great and sudden increase in the electric field resulting in disruptive discharges or 'flashes.' It is also known that the highest charge whether positive or negative is carried by light rain. It is therefore expected that during such drizzle there would be sources of atmospherics in the disruptive discharges or 'flashes' near the receiving point.

ESTIMATION OF THE SIGNAL-STRENGTH VALUES FOR GOOD RECEPTION AT DACCA ON 5 Mc. AND 10 Mc.

The average values of the daily maxima of the peak field-strengths of the atmospherics from the east-west direction on 5Mc. and 10Mc. were determined for May-June during the usual morning, afternoon and the night programme hours. In table III are given these averages :—

TABLE III

Field-strengths in Microvolts per metre

10 Mc.			5 Mc.		
Morning	Afternoon	Night	Morning	Afternoon	Night
8—12 A.M.	1—5 P.M.	7—11 P.M.	8—12 A.M.	1—5 P.M.	7—11 P.M.
5.83	7.20	7.50	22.03	26.21	27.25

In table IV are given the signal-strength values which will be 20 db above the averages of the peak field-strengths of the atmospherics on 5 Mc. and 10 Mc. Such signal-strengths can be regarded as standard values for good reception.

TABLE IV

Periods (May-June)	Signal-strength which is 20 db above the peak strength of the atmospherics	
	10 Mc.	5 Mc.
(1) Morning 8 to 12 A M.	58 microvolts/metre	220 microvolts/metre
(2) Afternoon 1 to 5 P.M.	72 ,,	262 ,,
(3) Night 7 to 11 P.M.	75 ,,	273 ,,

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REFERENCES

1 Chakravarty, S. P., Ghosh, P. B., and Ghosh, H., *Proc. I.R.E.*, **27**, p. 780 (1939); Chakravarty, S. P., *L'on de Elec.*, **18**, No. 207, p. 99, March (1939).

2 Chakravarty, S. P., and Paranjpye, B. H., *Jour. Ind. Inst. Science (Bangalore)*, **17 B** 1 (1934).

3 Khastgir, S. R., and Rao, Kameswar, *Proc. I.R.E.*, **28**, 511 (1940).

4 Khastgir, S. R., and Ray, *Science and Culture*, **5**, 772 (1940).

5 Espenschied, Anderson and Bailey, *Proc. I. R. E.*, **14**, 7 (1926).

6 Potter, *Proc. I. R. E.*, **19**, 1731, Oct. (1931), and **20**, 1512, Sept. (1932).

7 Schafer and Goodall, *Proc. I. R. E.*, **27**, 202 (1939).

8 Eccles, *Handbook of Wireless Telegraphy and Telephony*, p. 176 (1918).

9 Namba, *Proc. I. R. E.*, **21**, 238 (1933).

10 Mitra, *Science and Culture*, **3**, 496 (1938).

11 Mathur, *Proc. Nat. Acad. Sciences* (India), **7**, 222 (1937); Bajpai and Pant, *Ind. J. Phys*, **12**, 211 (1938); Ghosh, *Ind. J. Phys.*, **14**, 101 (1940).

12 Bajpai and Pant, *Ind. J. Phys.*, **12**, 211 (1938).

13 A. Venkat Rao Telang, *Proc. Ind.*, Science Congress, Paper No. 20 (1941).

14 Burch, C. R., and Bloesma, J., *Phil. Mag.*, **49**, 480 (1925).

15 Norton, K. A., *Proc. I. R. E.*, **24**, 1367 (1936).

16 Moullin, *Jour. I. E. E.*, **62** (1924).

17 Dellinger's Report on Radio Propagation Data, *Proc. I. R. E.*, **21**, 1419 (1933).

18 Appleton and Booghariwala, *Proc. Phys. Soc.* (Lond.), **47**, 1074 (1935).

19 *See* Whittaker's Modern Analysis, Chap. VI, Theory of Residue.